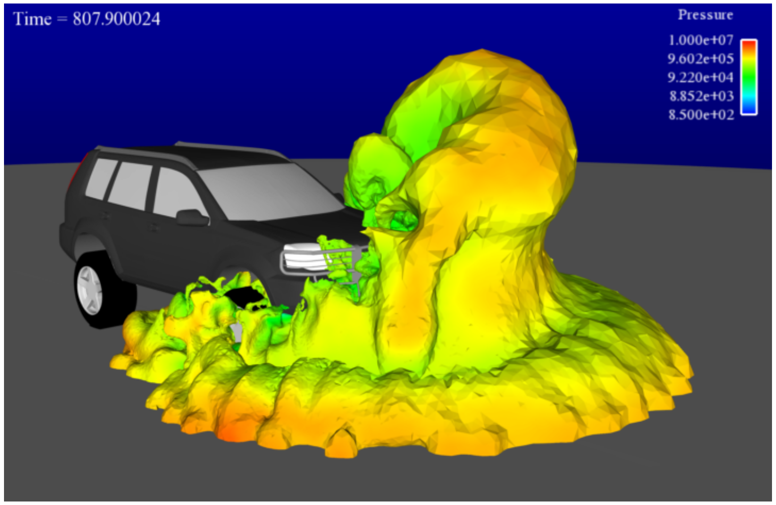
A Conformal, Fully-Conservative Approach for Predicting Blast Effects on Ground Vehicles



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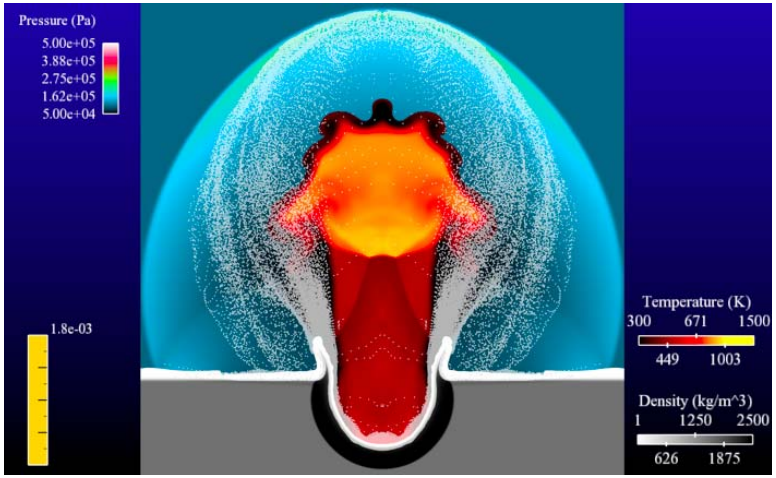

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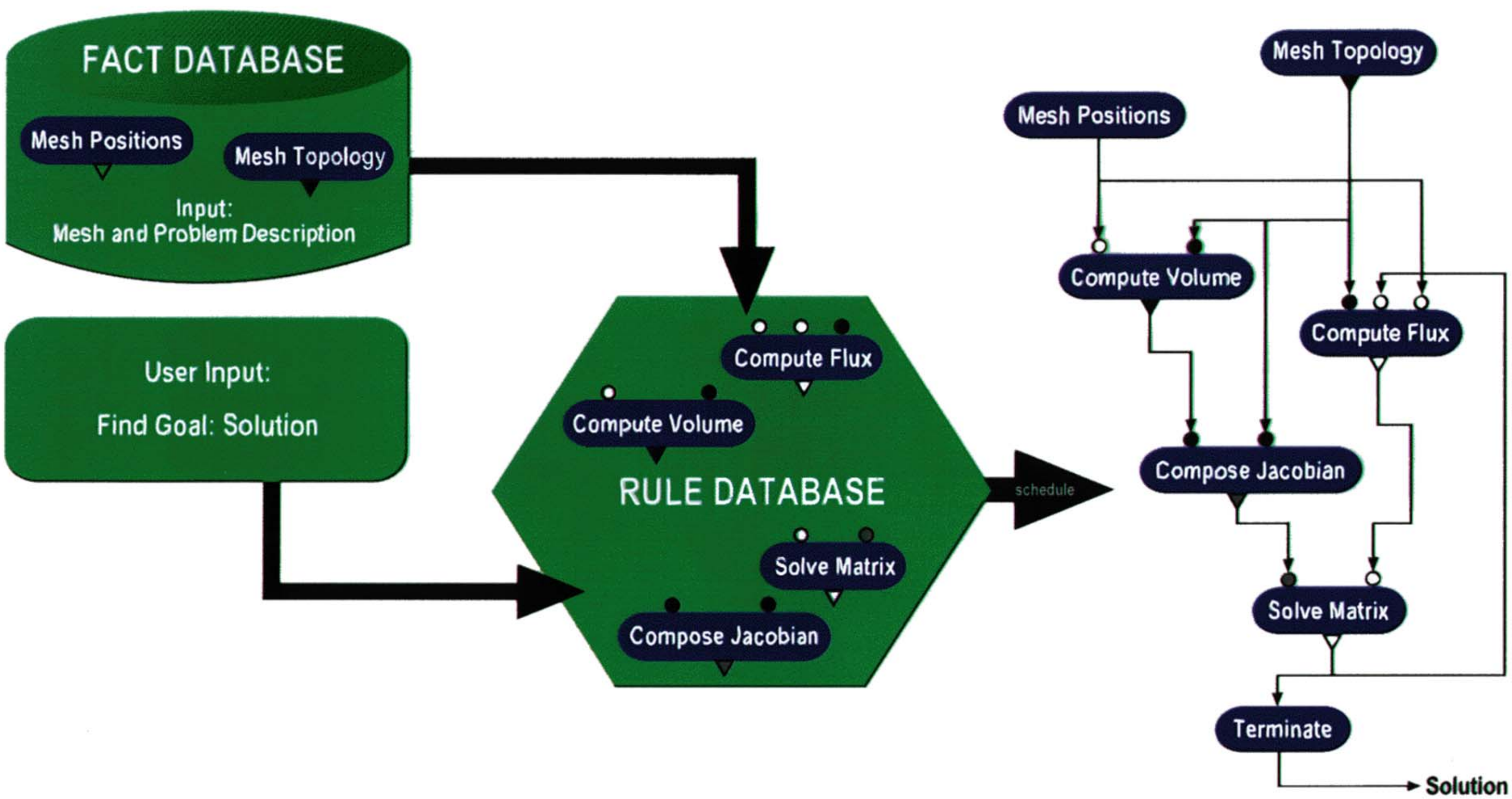
Loci/BLAST: Overview

- Based on Loci multi-physics code development framework
  - Treats applications as relational databases of *facts* (irregular data) and *rules* (procedures that operate on the data)
  - Provides automatic code generation, parallelization, dynamic memory management and cache optimization
  - Lowers cost of developing complex multi-physics applications
- Loci/CHEM: Parent of Loci/BLAST
  - Highly-parallel, full-featured Eulerian CFD code for chemically reacting flow simulations
  - Used by NASA, USAF, Army and Gov't labs along with Boeing and several small aerospace companies
  - Extensive V&V using MMS

Loci Paradigm

- Define computational kernels as rules
  - Framework assembles rules into applications at runtime and schedules execution



Loci Rules Example

- Loci rules mimic mathematical notation
  - Parallelization occurs automatically as Loci operates on collections of entities

```
// Numerically solve the partial differential equation: ∂u/∂t = ν ∇ · ∇u
// Using Forward Euler time integration

// Set Initial Value:  u^{n=0} = u_initial
$rule pointwise(u{n=0}<-u_initial) { $u{n=0} = $u_initial ; }

// Forward Euler time-step:  u^{n+1} = u^n + ΔtR^n
$rule pointwise(u{n+1}<-u{n},R{n},dt) { $u{n+1} = $u{n}+$dt*$R{n} ; }

// Define residual (diffusion operator):  R = ν div(grad(u))
$rule pointwise(R<-nu,div(grad(u))) { $R = $nu*$div(grad(u)) ; }
```

Loci Multi-Physics Framework

- Advantages:
  - AI detects bugs introduced by logically inconsistent specification of numerical models
  - Decouples computations from their mappings onto distributed data structures
  - Databases of rules become knowledge bases for composing increasingly complex simulations
  - Parallelization effort is greatly simplified and is automatic
  - Optimizes low level calculations for higher levels of cache use

Loci/BLAST Capabilities

- Cell-centered, finite-volume method for general polyhedral elements
  - Overset meshes with automated hole cutting
- 2nd-order TVD Runge-Kutta time integration
- Approximate Riemann Fluxes (HLLE, HLLC)
  - Robust mixture model for multi-material flows
- Multiple Equations of State
  - Perfect Gas
  - Novel tabular EOS based on Bezier surfaces
  - JWL EOS for explosive materials
  - Linear Barytropic EOS for solids
  - Multi-phase EOS for soils
  - Modified Tait EOS for water

Loci/BLAST Capabilities

- Coupled Lagrangian particle model for particulate flows
- Prescribed burn and ignition and growth reactive burn models for explosive detonation
  - Secondary combustion model for non-ideal explosives
- One-way and two-way coupling with LS-DYNA for Fluid-Structure Interaction (FSI) simulations
  - Conservative load transfer between Loci/BLAST and LS-DYNA
  - Robust deformation of CFD mesh in response to structural deflection
  - Simple socket protocol provides communication between the two applications

Loci/BLAST Soil Model

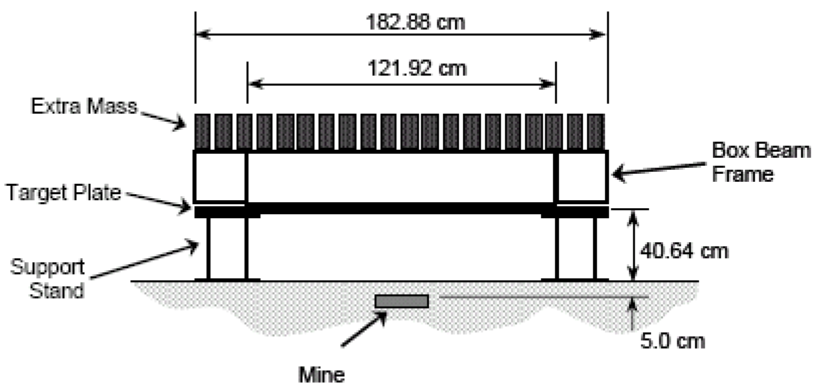
- Soil modeled as mixture of solids, water and air
  - Solids composed of organic mater, clay particles, and sand
    - Currently, solids have same elastic modulus as quartz
    - No material strength in current model
  - Water modeled using Modified Tait EOS
  - Air modeled as a perfect gas
  - Mixture mass fractions derived assuming that the soil pore volume can be determined from dry soil
  - Current model works best for dryer materials
- Soil model validated using mine impulse pendulum results

Underbody Blast Applications

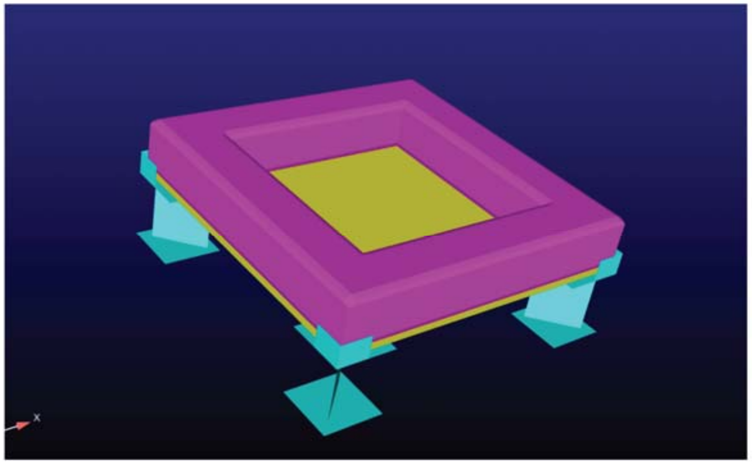
- Loci/BLAST-LS-DYNA two-way coupling validated using DRDC Plate experiment
  - DRDC plate deflections compared to results of Williams et al (7th International LS-DYNA Users Conference, 2002) for TACOM Impulse Loading model (Westline, 1972)
- TARDEC Generic Hull geometry used to verify coupling for realistic configurations
  - Qualitative results only

DRDC Plate Experiment

- Large weight used to restrict target
- 6kg C4 at 5 cm DOB
- 31.75mm thick AL5083-H131 target plate
- Soil density of 2300kg/m^3
- Various soil compositions tested
- Tabular EoS
- Johnson-Cook material strength inputs
- 4-noded Belytschko-Tsay shell elements
- 0.5 cm surface resolution



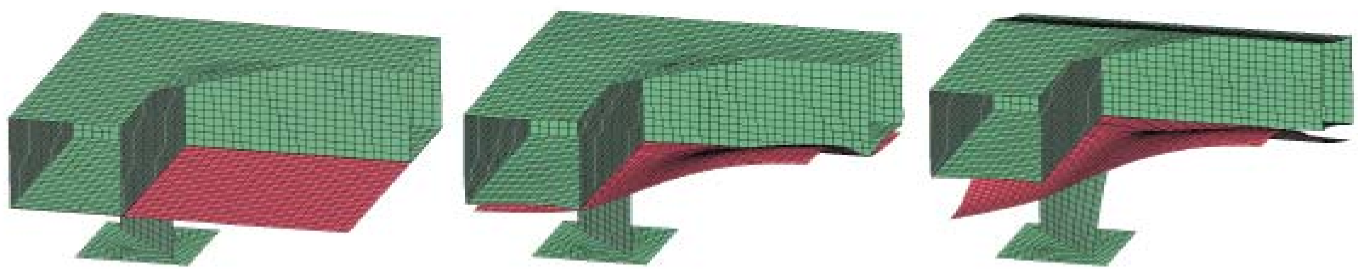
DRDC Experiment (Williams, 2002)



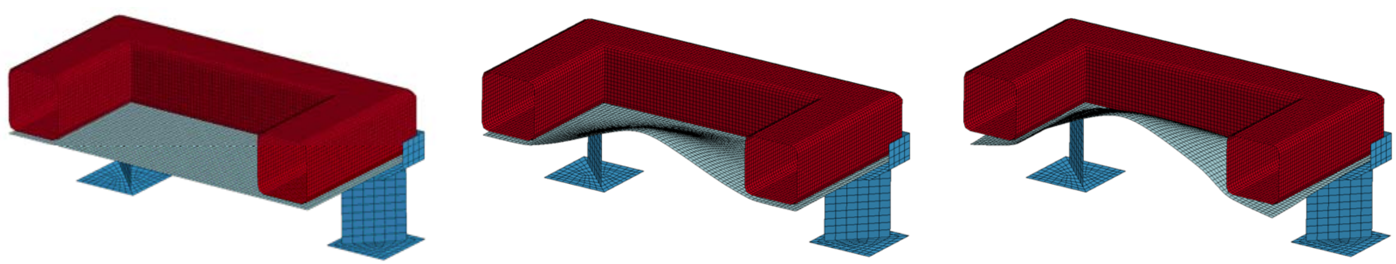
LS-DYNA Model

DRDC Plate Response

Initial t=1ms t=2ms

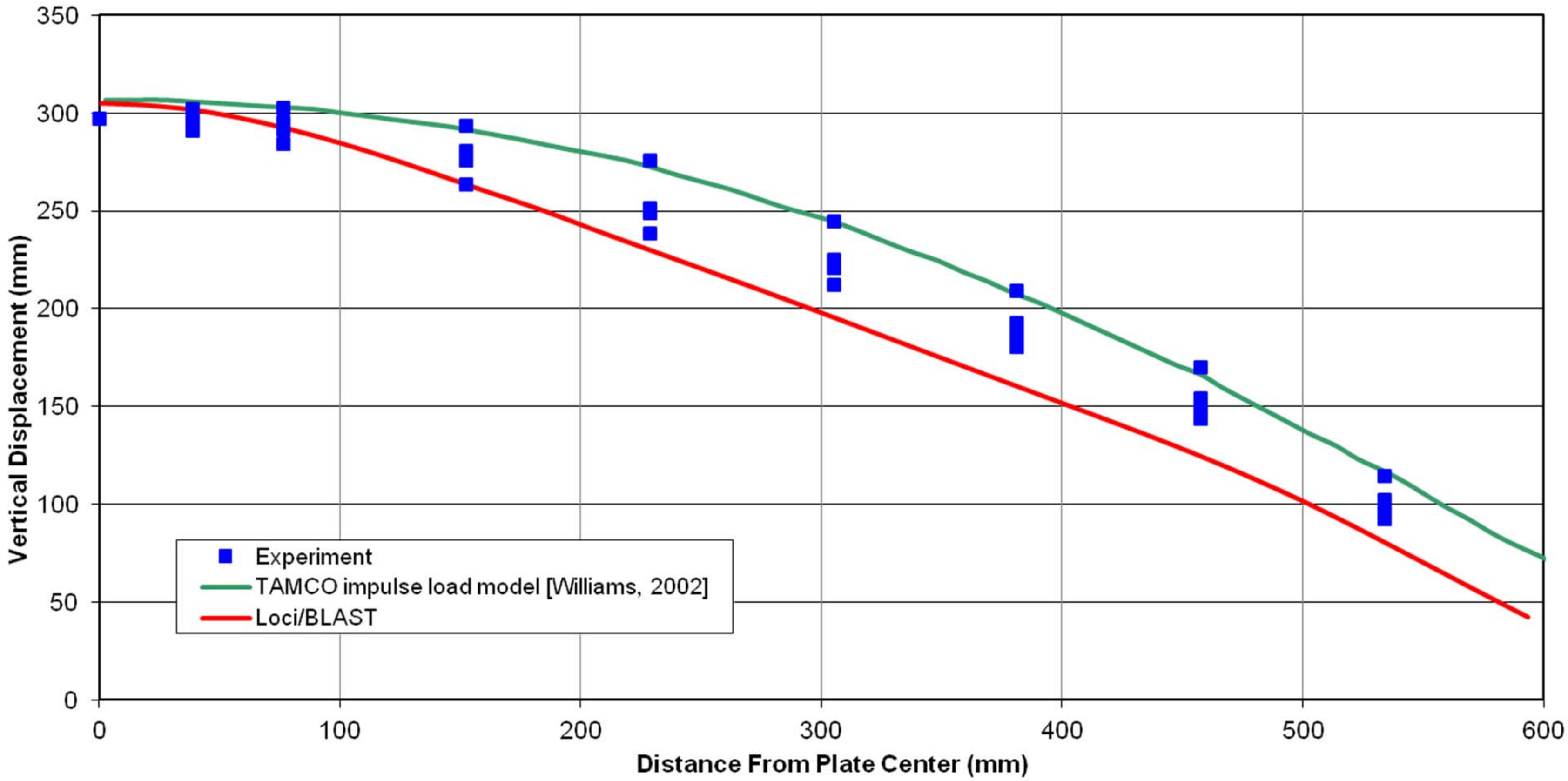


Williams (2002)



Loci/BLAST – LSDYNA

DRDC Plate Response



TARDEC Generic Hull

- Geometry represents a notional Army vehicle
- Test conditions:
  - Charge: 6kg cylinder of C4
    - STANAG 4569 Level 2 mine blast threat
  - 2 in DOB
  - Soil taken to be dry sand (70% quartz by volume fraction)
- Two way-coupled Loci/BLAST – LS-DYNA analysis
  - Conformal meshes
  - 192 Loci/BLAST processors, 1 LS-DYNA processor

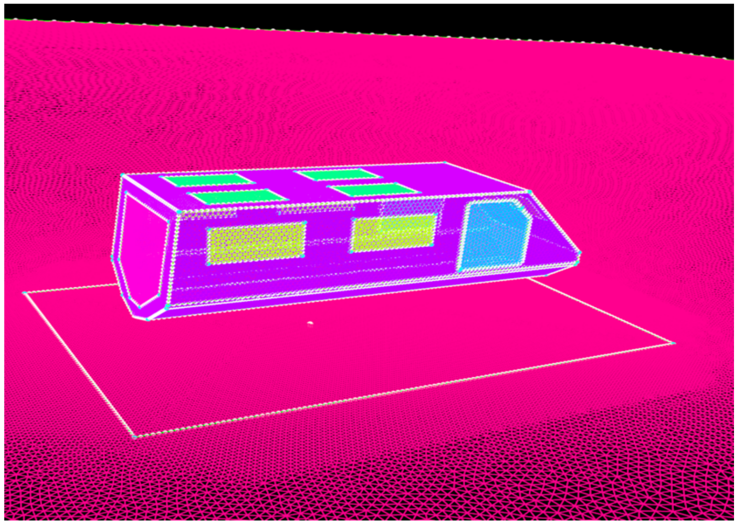
TARDEC Generic Hull

Three different near-body spacings used in CFD mesh:

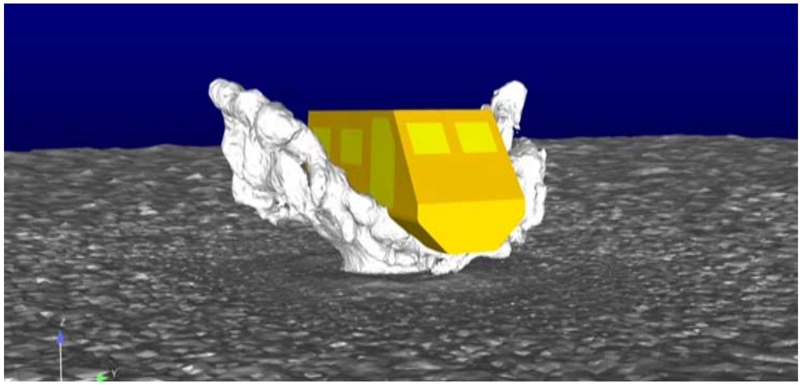
Coarse (5.0 cm – 12M cells)
Medium (2.5 cm – 29M cells)
Fine (1.25 cm – 57M cells)

Soil extends 3 ft below ground plane

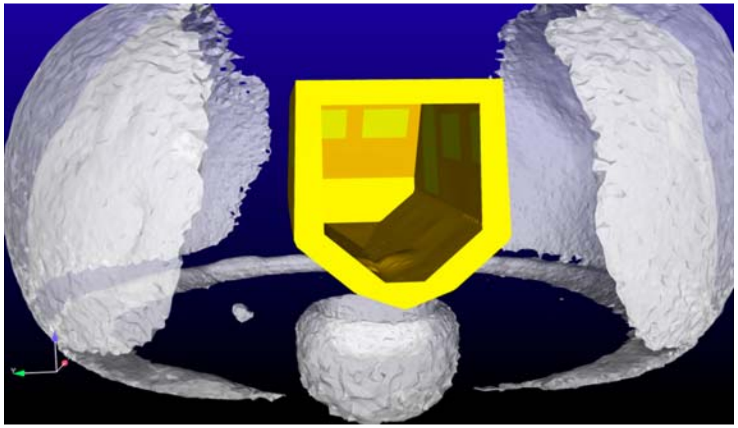
Simulation time = 5ms



Mesh

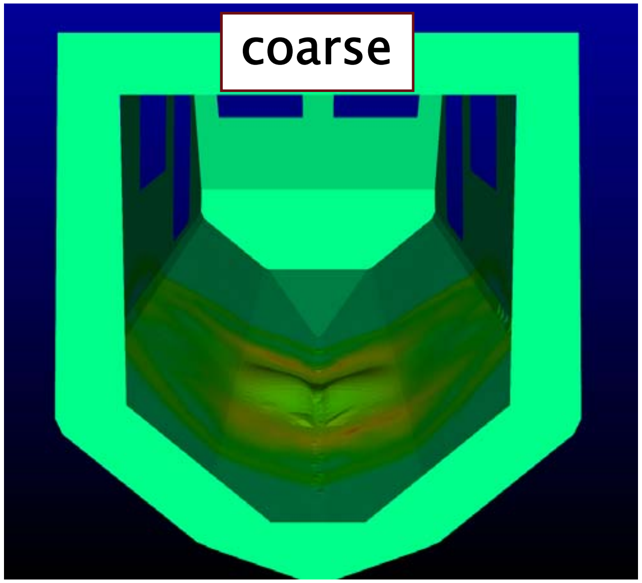


Soil volume fraction t=5 ms

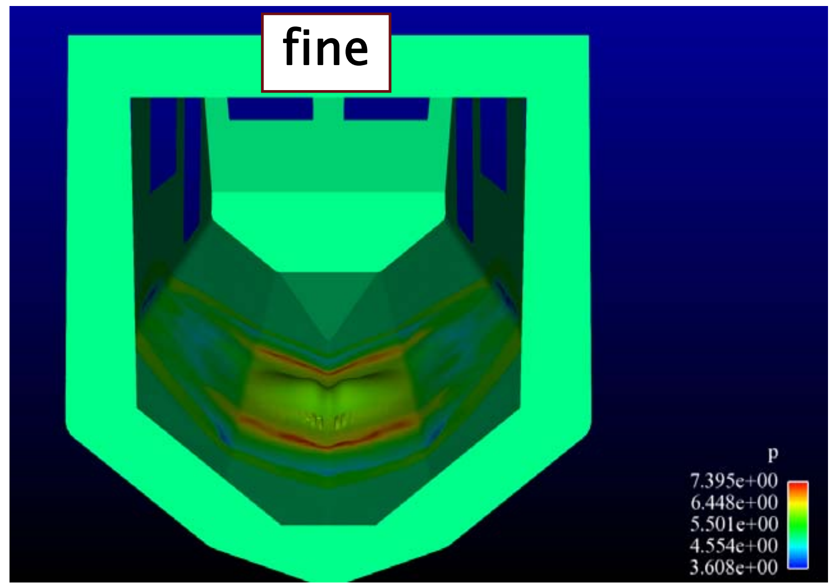


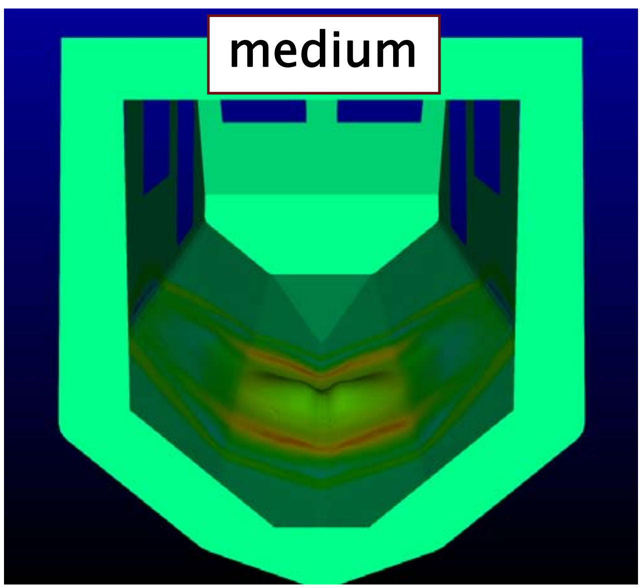
Blast front t=5 ms

Mesh Sensitivity: Hull Pressure

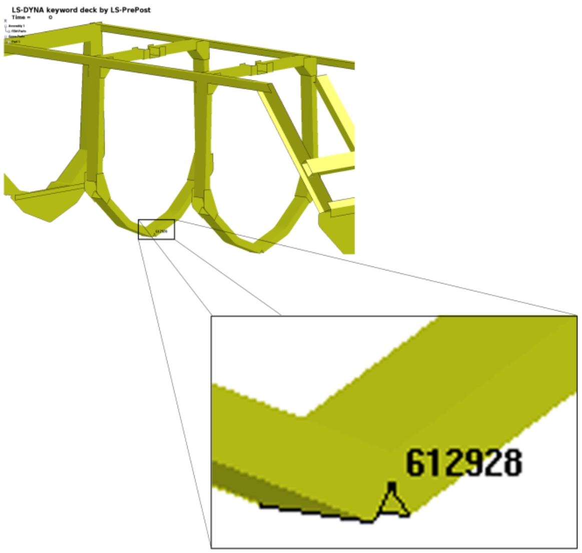


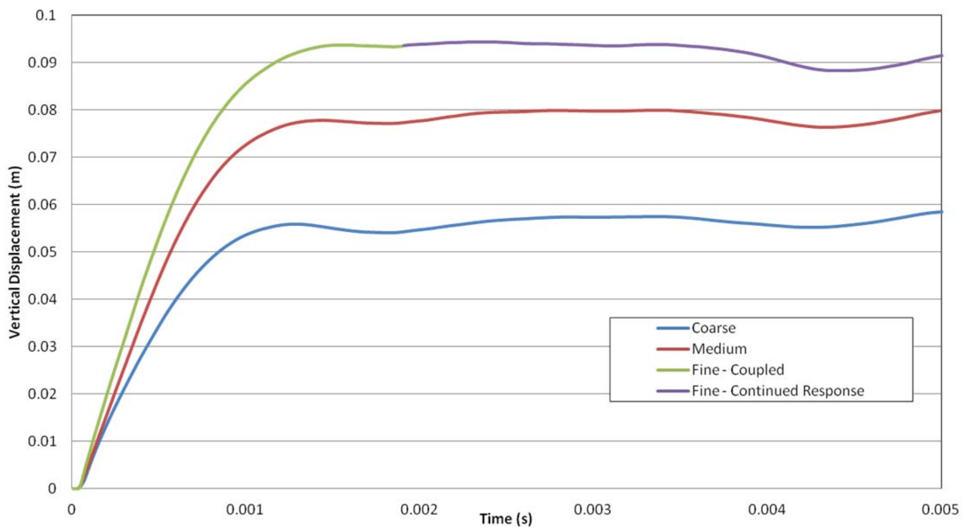
Log_{10} hull surface pressure -1ms

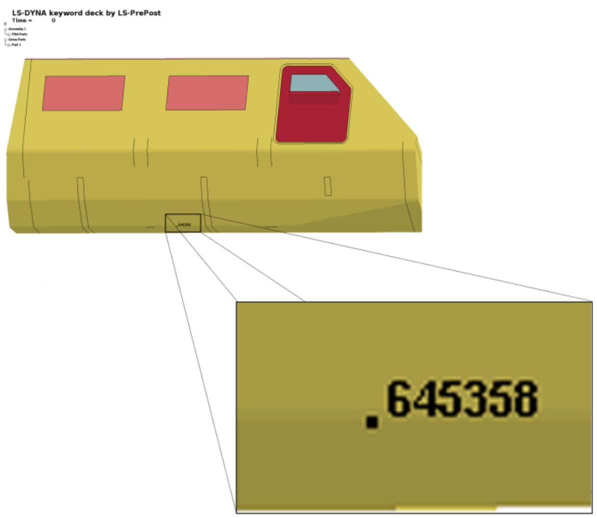


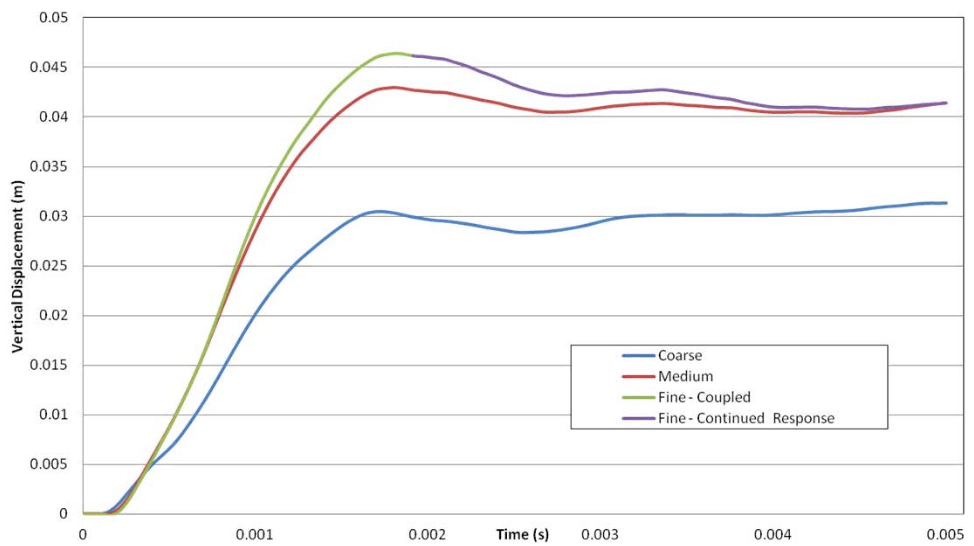


Frame and Hull Displacements

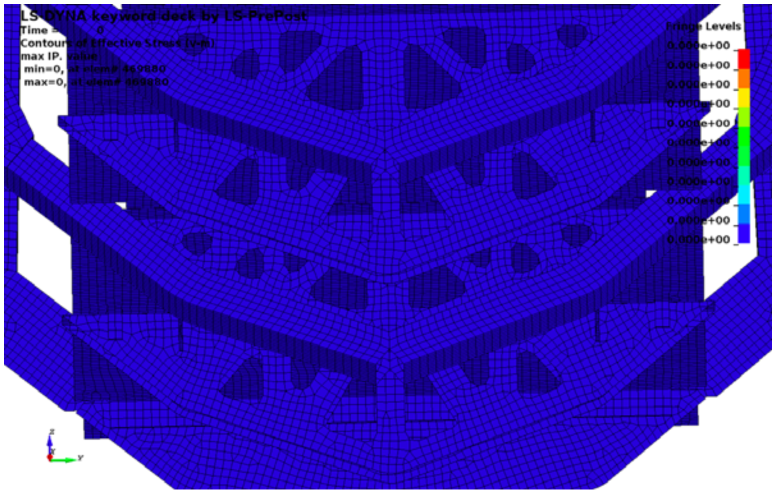




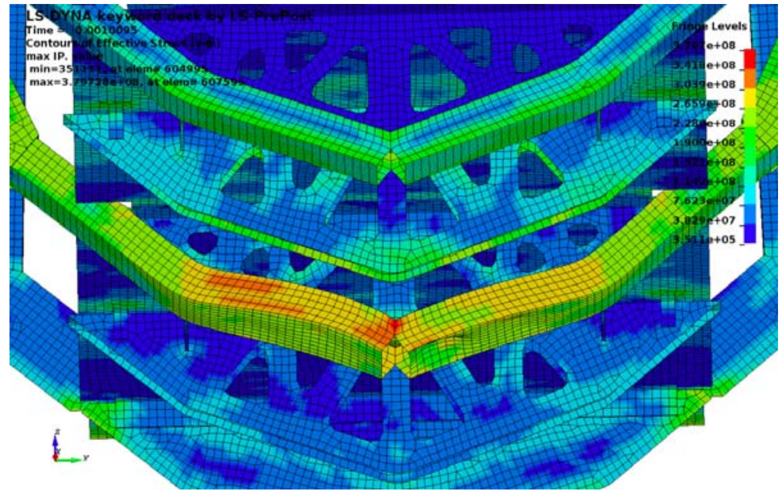




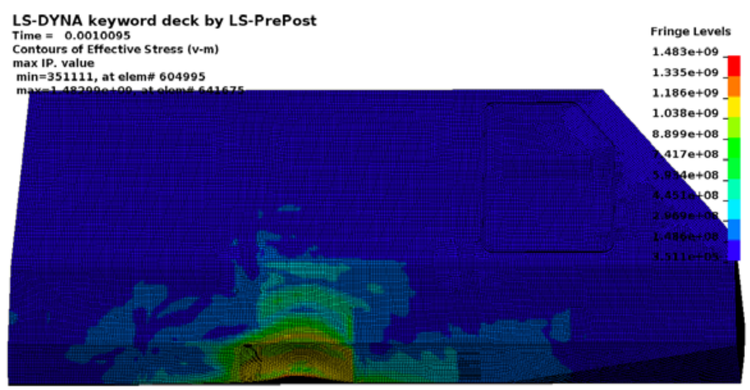
Frame and Hull Stresses t=1.5 ms



Initial frame configuration



Frame stress and deflection



Hull stress and deflection

Conclusions and Future Plans

- Loci/BLAST is a modern high-fidelity blast simulation tool with unique features not found in other codes
- Successfully applied the code to two-way coupled underbody blast simulations
  - Also blast in urban environments
- Future plans
  - Continue verification and validation efforts
  - Add adaptive mesh refinement
  - Build a native structural dynamics module using Loci framework that will tightly couple with CFD components

Availability

- Loci/BLAST and Loci/CHEM are licensed as open source software and are available free of charge. They are distributed using gpg encryption to approved users under U.S. ITAR restrictions.
  - http://www.simcenter.msstate.edu/software.php
- The Loci framework is open source and available from:
  - http://www.cse.msstate.edu/~luke/loci/
- Contacts
  - Ed Luke
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  - David Thompson
    dst@cavs.msstate.edu
  - Richard Weed
    rweed@cavs.msstate.edu

Other Loci Applications

- Loci/CHEM: Chemically reacting compressible flow solver.
  - Currently in production use by NASA for the simulation of rocket motors, plumes, and vehicles
- Loci/DROPLET: Eulerian and Lagrangian multiphase solvers
- Loci/STREAM: pressure-based solver
  - Developed by Streamline Numerics and University of Florida
- Loci/FemLib: Finite-element linear elasticity thermal stress solver
  - Developed by the Cornell Fracture Group
- Loci/Radiation model: CA-DOM non-gray radiation modeling
  - Developed in collaboration with CFDRC
- The Loci/THRUST: High-Order Discontinuous Galerkin Navier-Stokes Solver
- Various multidisciplinary simulation tool created by composing the above solvers